Phase 1- Three-Dimensional Turbulent Multiphase Measurements Using Shadow Particle Image Velocimetry Coupled with Neural Networks for Pattern Recognition

DOE Project DE-FG07-98ID13638

Principal Investigator: Yassin Hassan, Texas A&M University
Co-Principal Investigator: Rube Williams, Texas A&M University

Report Period: June 1,1998-May 31,1999

On this NEER project, Texas A&M University has investigated and applied a three-dimensional particle image velocimetry flow measurement technique to the study of two-phase bubbly flows. An ART-2 neural network tracking scheme was developed and implemented to track the two-dimensional digital experimental data. The two-dimensional images were reconstructed into a three-dimensional instantaneous velocity field, with a stereoscopic reconstruction technique. Hardy Interpolation techniques were used to interpolate the velocity data in areas where few velocity vectors were obtained. A preliminary study of the turbulence structure of the two-phase flow was performed with conditional sampling techniques based on specified bubble trajectories and positions. The vorticity structure of the liquid fluid was determined. Moreover, it is a project goal to use Shadow Particle Image Velocimetry (SPIV) techniques to measure and obtain the size, velocity and trajectory of the bubbles and to simultaneously measure the surrounding velocity field with the PIV technique. Achievement of this goal will aid in the development of the constitutive closure relations needed for computational fluid dynamics (CFD) and best-estimate thermal hydraulic codes. These results can also be used in many other applications, such as dynamic transport of pollutants in the environment or measuring the dispersion of the waste. It could help to develop techniques to monitor radioactive or mixed hazardous wastes in the soil or water. In addition, the developed imaging and pattern recognition techniques for this study can be applied in medical imaging and biomedical applications.

1. **Objective:** Modify the existing test facility to provide a two phase bubbly flow with various superficial velocities of air and water flows.
Accomplishments: The construction of a bubbly flow test facility was completed. Various pipe diameters were tested, to determine the optimum sizes. Pipe diameters of 1.2 cm and 1.1 cm were used in the final tests. It was found that these sizes of pipe had the best diameter and thickness to reduce the light refraction effects, would give a full view of the pipe in the camera images, and would be suitable for the flow field structures being measured. The test facility includes a filter for eliminating contaminants from the fluid prior to the measurements being taken. The test section of the pipe is enclosed inside a clear box to help eliminate refraction effects. An elevated head tank is used to provide a constant flow through the pipe. The air is injected at the entrance to the pipe with a small needle. Tracer particles of specific gravity of 1.02 are used as the seeding for the water (Figure 1).

2. **Objective:** Determine the optimum locations of the cameras to achieve the least measurement errors.
Accomplishments: The positioning of the cameras for the measurements is very important. Different configurations were tested, including two cameras on two different sides; and three cameras on one side, with the fourth being on the perpendicular side. The advantage of the first configuration is that two simultaneous views can be obtained of the same viewing volume at different angles. The second configuration allows, more velocity vectors to be matched and the fourth camera can be utilized for Shadow Particle Image Velocimetry (SPIV) measurements. For the SPIV measurements, the second configuration will be used. The optimum angle between

the cameras was determined. It was found that an angle of 20 degrees between two neighbor cameras achieves the minimum measurement errors (Figure 2).

3. **Objective:** Develop the neural network algorithm for camera calibration to determine stereo imaging geometry.
Accomplishments: Two different calibration methods were tested. The first is a developed multilayer neural network, and the second is based on a Direct Linear Transformation (DLT). It was found that the second method achieved accurate results. The transformation from the three-dimensional (3D) world point coordinates to the two-dimensional (2D) perspective projection, generated 11 unknowns. These unknowns were determined by utilizing the Direct Linear Transformation method.

4. **Objective:** Validate the calibration scheme.
Accomplishments: For this investigation, 546 points were used for the calibration. The points were used to solve the perspective equations, using a least squares method for each camera. These equations are the ones known as the Direct Linear Transformation (DLT) method.

Once the unknown parameters are determined, there is a relationship between world and image points for each camera. To uniquely determine the three world coordinates of an image point we need at least two images of that point from cameras at different view angles. By using the image coordinates of a point from the two cameras, and the already known variables for each camera, a system of 4 equations are solved for the unknown x, y, and z, by using least squares.

The accuracy of the velocity components were estimated from the calibration. The root mean square (r.m.s.) error in each direction is about 1.04 pixels in X-direction; 2.43 pixels in Y-direction; and 0.98 pixels in Z-direction. The error in Y-direction was computed from the combined errors from two cameras, assuming the error from each camera is independent. By adding the error resulting from the calibration process, and the spatial resolutions given above, the r.m.s. errors for each velocity component, in the world system of coordinates, are: 4.1% in the x-component; 9.8% in the y-component; and 2.4% in the z-component. These values are estimated with respect to the maximum velocities, and for a camera framing rate of 60 Hz.

5. **Objective:** Identification of particle image centers by using the developed recognition routines and matching algorithms.
Accomplishments: A thresholding program was developed to separate the particle images from the background in each image. The particle images are used to identify the velocity of the surrounding local fluid. The particles are distinguished from the background by their relative gray scale intensity to a local surrounding area. The centroid of each spot area is then calculated. A thresholding mask and the area magnitude of the image are used to distinguish the particles from the bubbles.

6. **Objective:** Analysis of the primary data of simultaneous 3-D two-phase velocities.
Accomplishments: A preliminary transient analysis was performed to delineate the bubble dynamics for a single bubble rising in stagnant water in a circular pipe using a whole-volume, three-dimensional particle image velocimetry flow measurement system. The liquid velocity field surrounding the bubble was acquired and the velocity vectors averaged to obtain the time-dependent averaged velocity field. The preliminary measurement results show that the mean kinetic energy in the measurement volume reaches its maximum during the bubble presence in the viewing volume. During the next 16.67 ms, 33.33 ms after the bubble leaves the volume, the mean kinetic energy is higher for bubble trajectories rising close to the pipe wall (Figure 3).

7. **Other Accomplishments:** Several publications are being presented at the ANS, and ASME conferences:

- Ortiz-Villafuerte, J., Hassan Y.A., and Schmidl, W.D., "Bubble Shape Identification Using Shadow Particle Image Velocimetry Technique," presented at the 1998 ANS Winter Meeting, November 15-19, 1998, Washington, DC, and published in ANS Transaction, Vol. 79, pp.357-360, 1998.
- Ortiz-Villafuerte, J., Schmidl, W.D., and Hassan, Y.A., "Three-Dimensional Experimental Study of the Wake of a Bubble Rising in Stagnant Liquid," to be presented at the 1999 ANS Annual Meeting, June 6-10, 1999, Boston, Massachusetts and to be published in ANS Transaction, Vol. 80, 1999.

A Ph.D. student, Mr. William Schmidl, completed his Ph.D. May 1999 under the support of this DOE grant. Details of the project results can also be found in the Ph.D. dissertation:

- Schmidl, William, "Three-Dimensional Experimental Investigation Of The Two-Phase Flow Structure In A Bubbly Pipe Flow," Texas A&M University, Ph.D. Dissertation, May 1999.

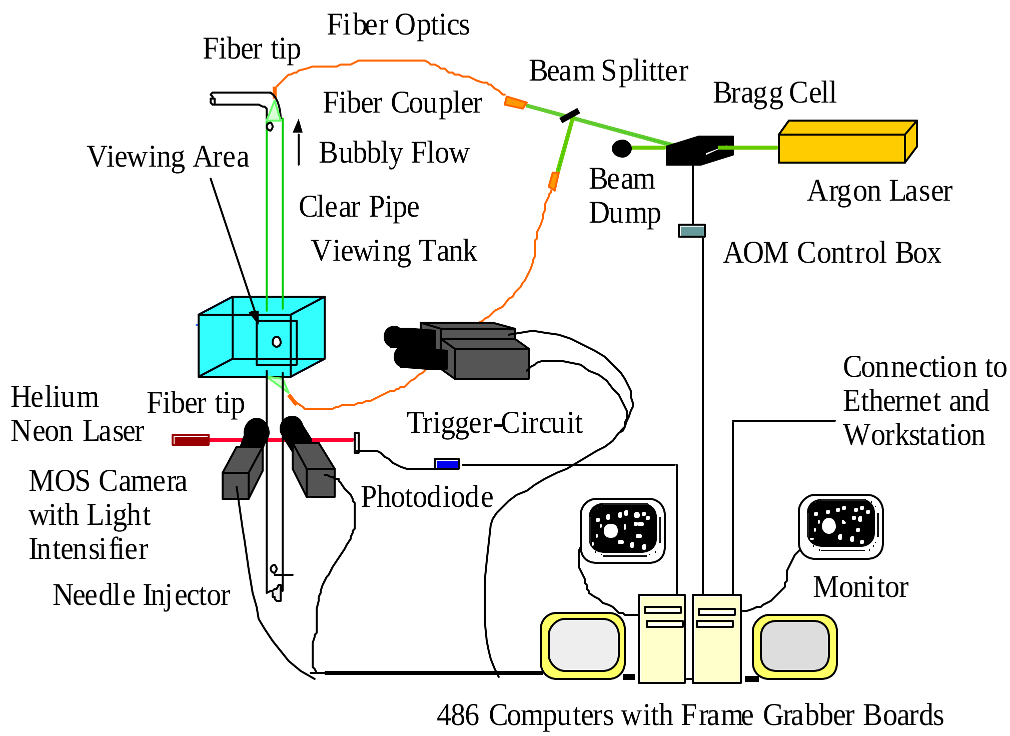

Figure 1. Data acquistion system setup.

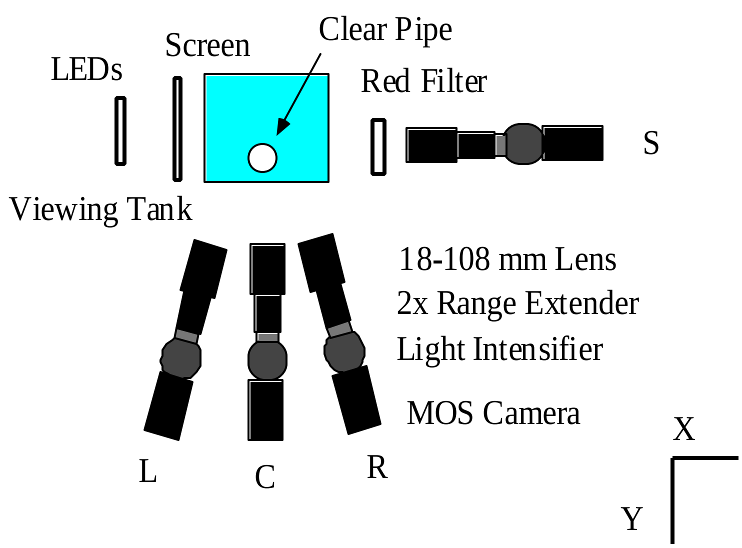

Figure 2. Camera Arrangement Top View.

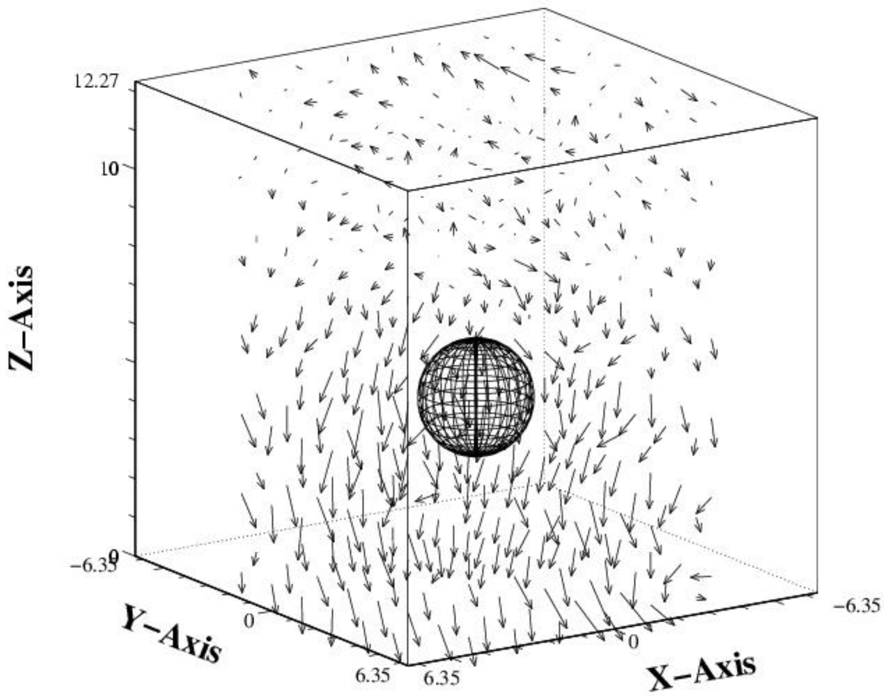

Figure 3. Velocity field at t_p = 16.7 ms.